
Behavior of intense beams simulated with Simpsons

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1. Space charge effects in RCS and MR.
2. Saturation of simulation parameters.
3. resonance crossing of incoherent and coherent tune
in 2D and 3D.

Two aspects of space charge effects in a synchrotron

JHF two synchrotrons are a typical example.

@ 3GeV RCS

Bunch shape as well as transverse emittance is transient,
because

- fast acceleration
- quick change of longitudinal bunch shape
- painting injection

Then, stability of core as well as tail and halo becomes an issue.

@ 50GeV MR

Bunch shape is well defined, usually matched to the lattice and
RF bucket,

Then, slow and continuous halo formation becomes an issue.

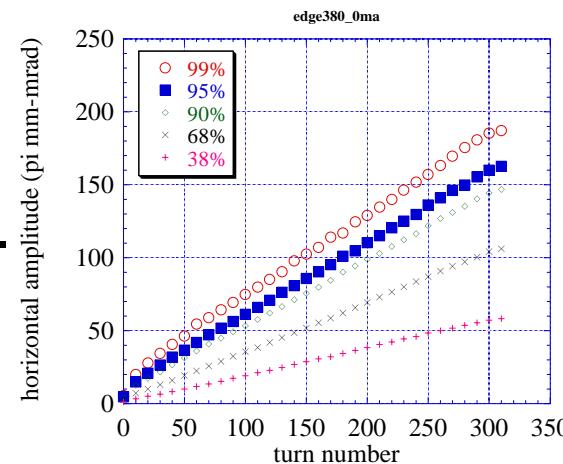
Preliminary simulation results of painting (2D)

Anti-correlated painting*
doesn't work as expected
with space charge effects.

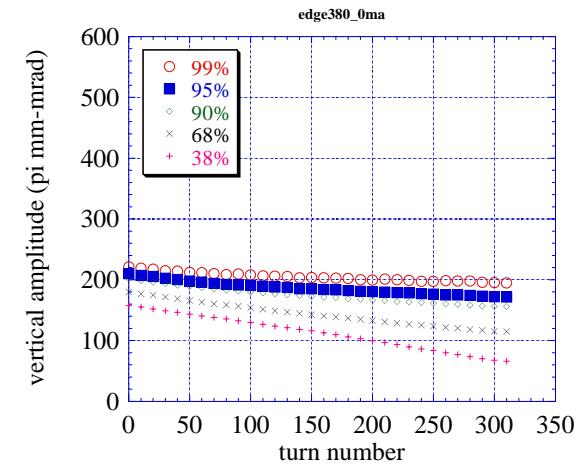
Coupling between H and
V changes the picture.

*start from small horizontal and
large vertical amplitude.

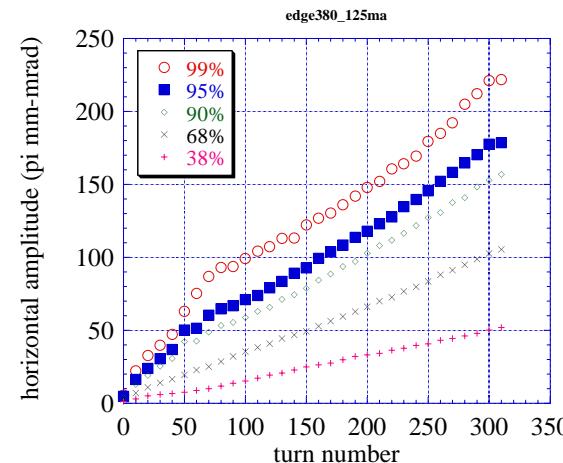
0mA H



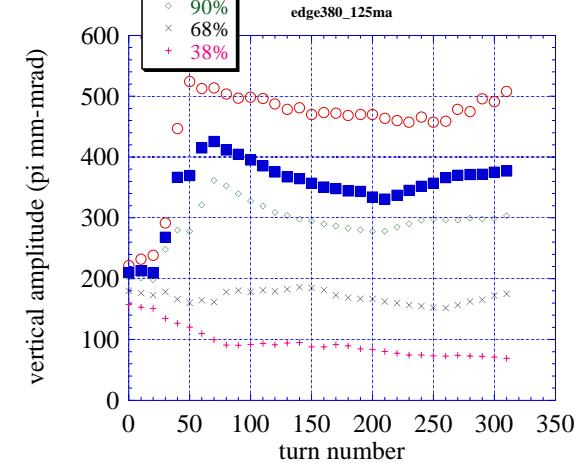
V



50mA H



V



Space charge effects on 50 GeV MR

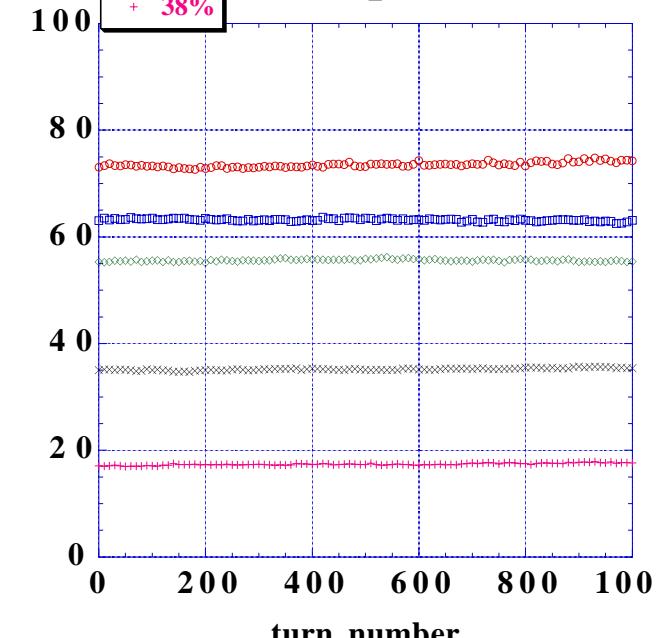
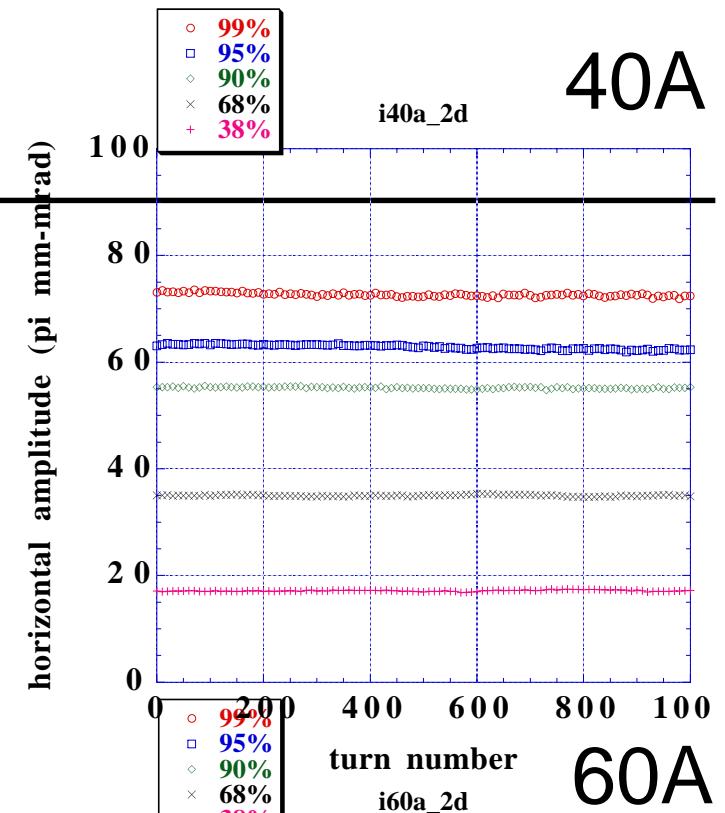
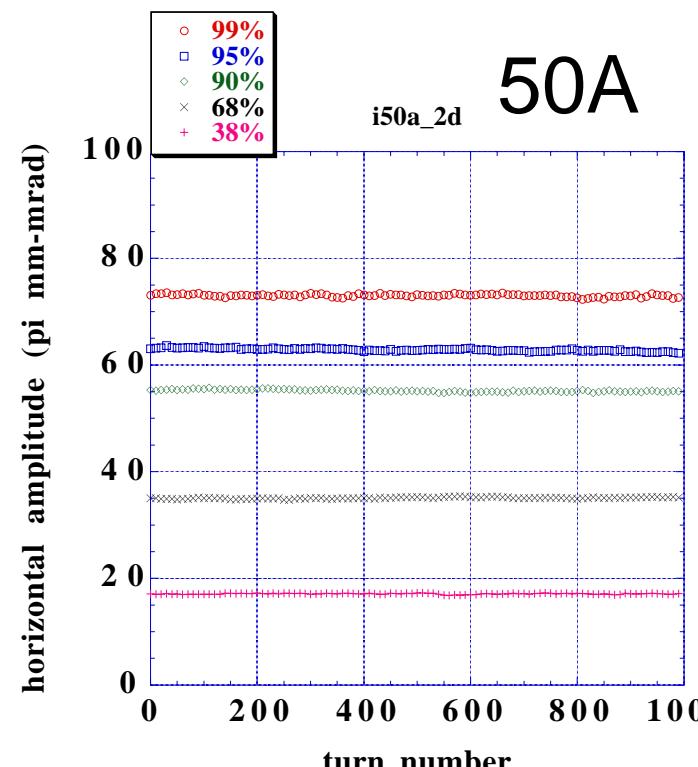
- emittance is rms matched to the lattice functions.
- bunch shape is matched to an RF bucket in 3D simulation.

What will happen in core and tail particles in that case?

Intensity dependence (H: 2D)

- bare tune is (22.32, 22.25)
- incoherent tune shift is -0.17 at 50A

No growth in horizontal at 40, 50, 60A.

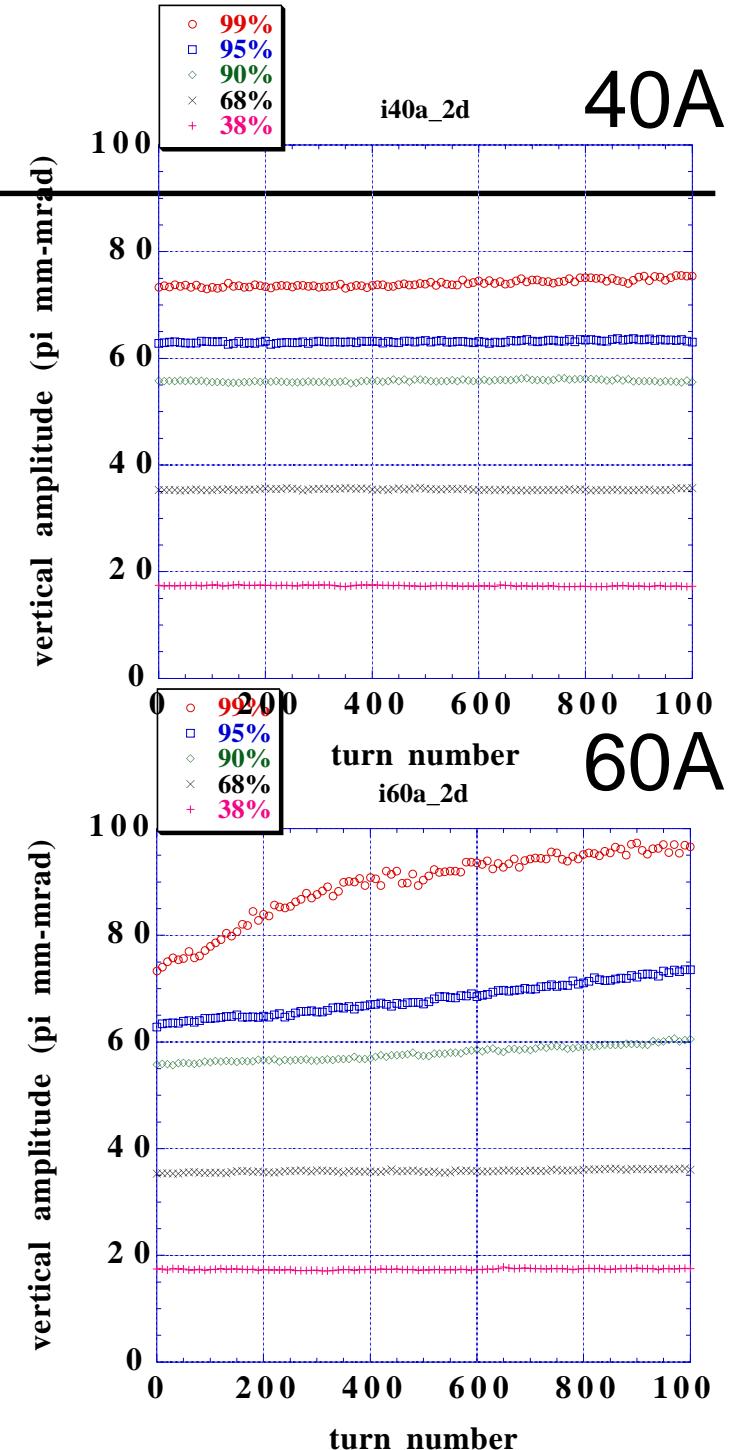
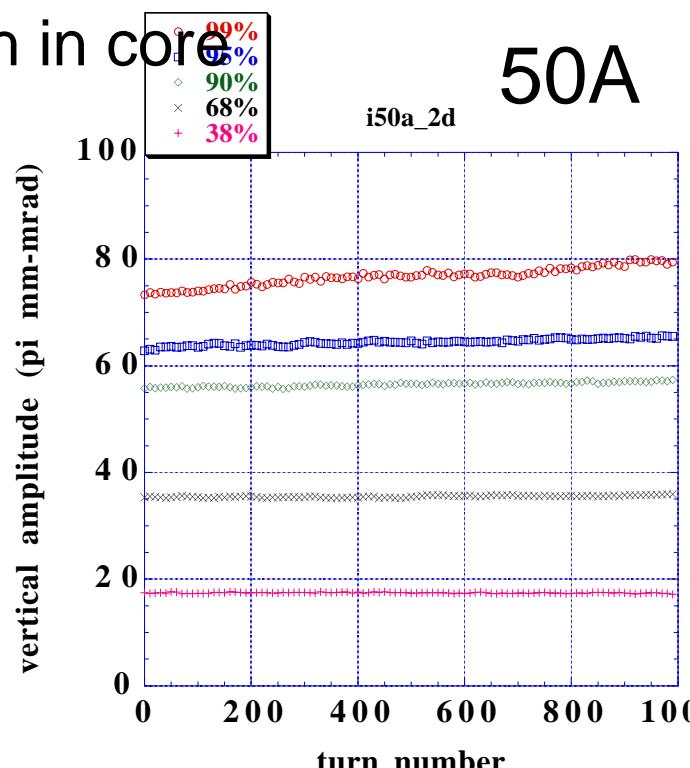


Intensity dependence (V: 2D)

- bare tune is (22.32, 22.25)
- incoherent tune shift is -0.17 at 50A

Some growth in vertical tail beyond 50A.

But still no growth in core



Remarks

- In horizontal direction, there is no growth in 2D simulation.
- In vertical, there is a tail growth beyond 50A ($\delta v = -0.17$).
- Tail part has more growth than the core although the tune shift is maximum at the core.

Check of saturation of 2D simulation parameters

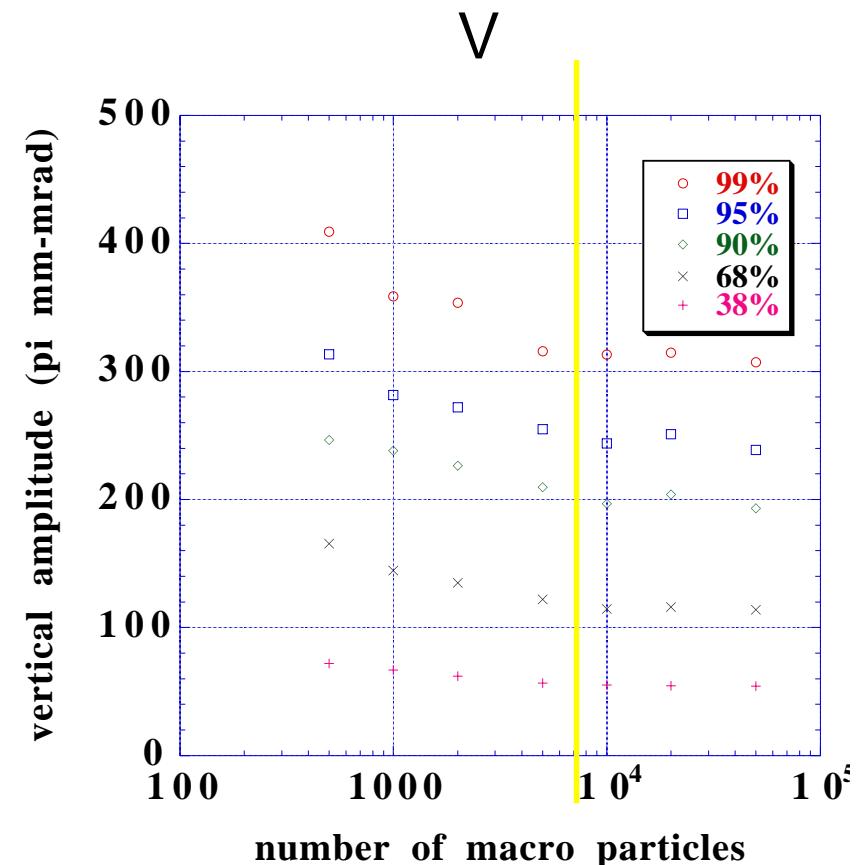
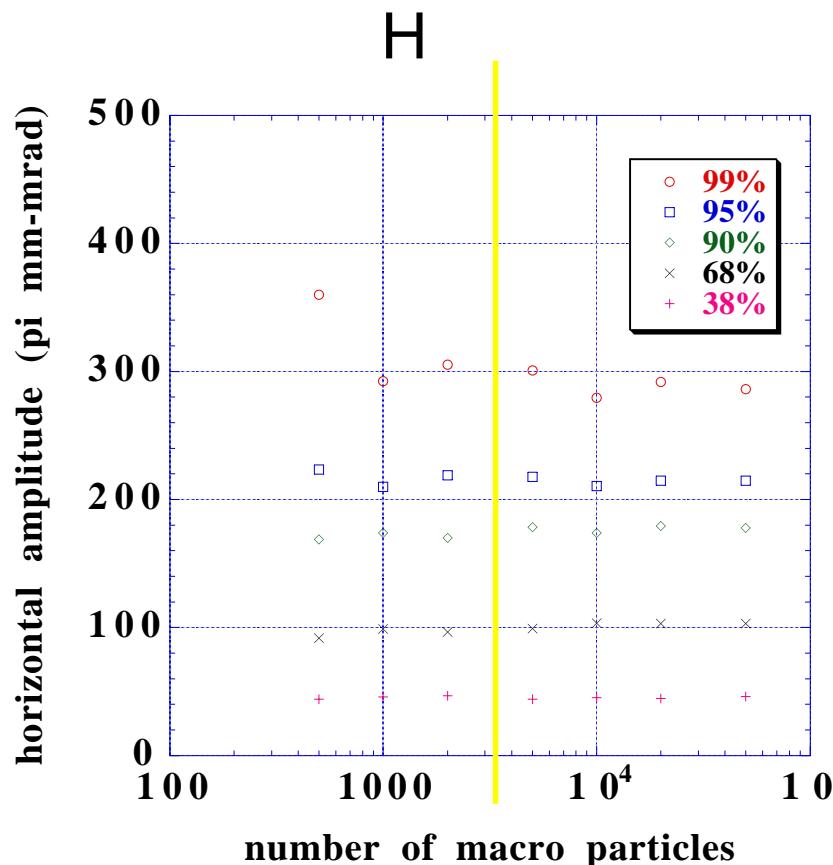
Simpsons uses the PIC technique with macro particles.

- # of macro particles
- # of radial grids
- # of decomposed azimuthal modes
 - Simpsons uses cylindrical coordinates and decompose modes in azimuthal direction.
- time step of integration
- single particle behavior

number of macro particles

nrg=50, mmode=16, ds=1m

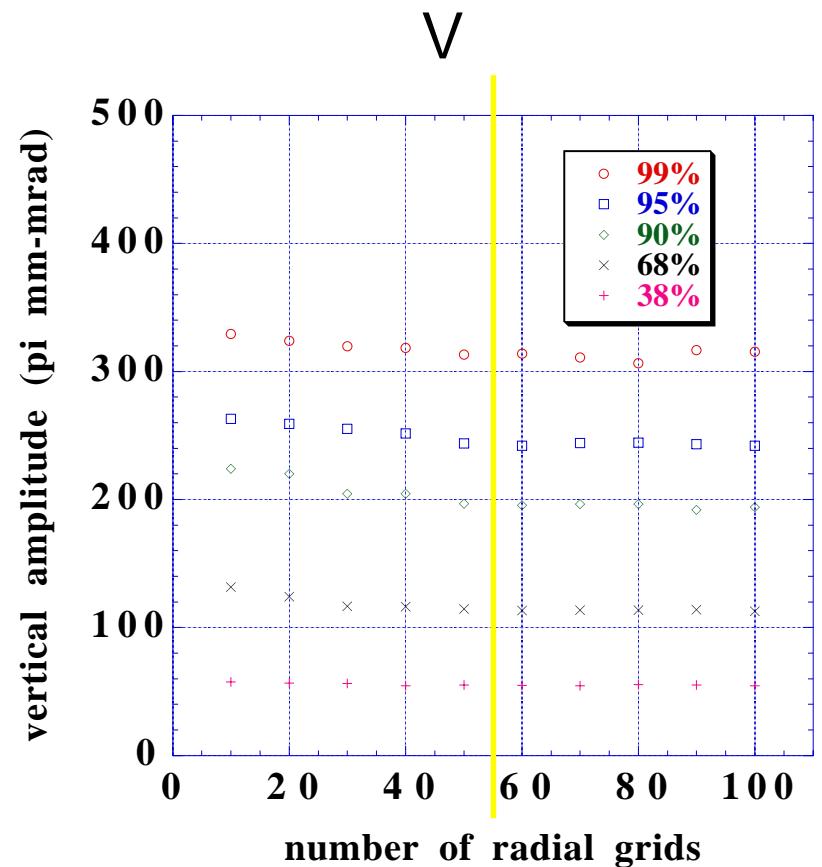
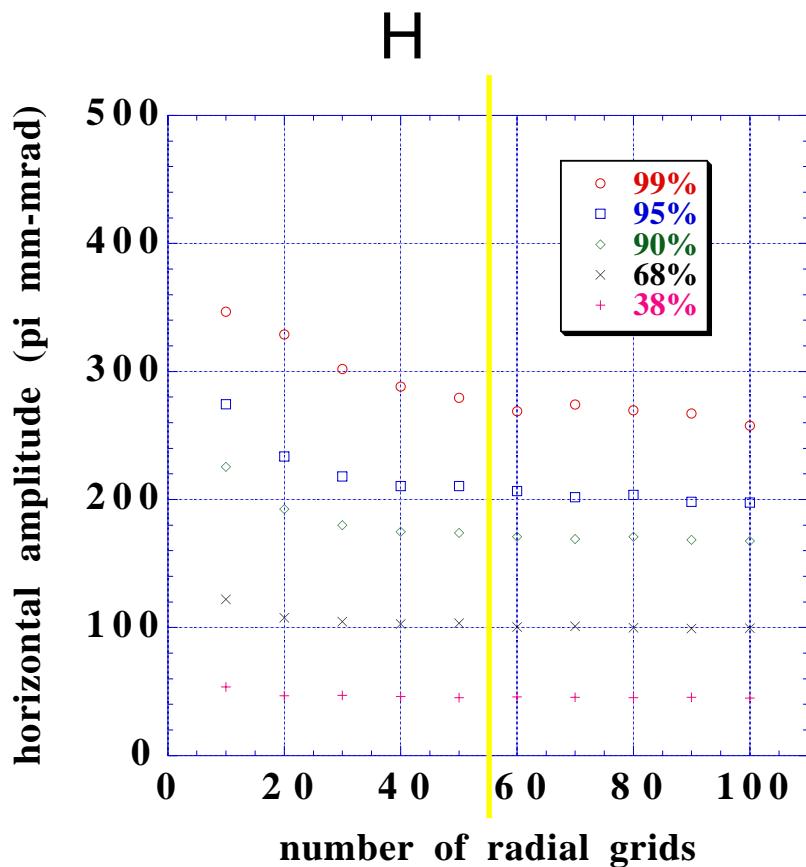
20A, 99%Q



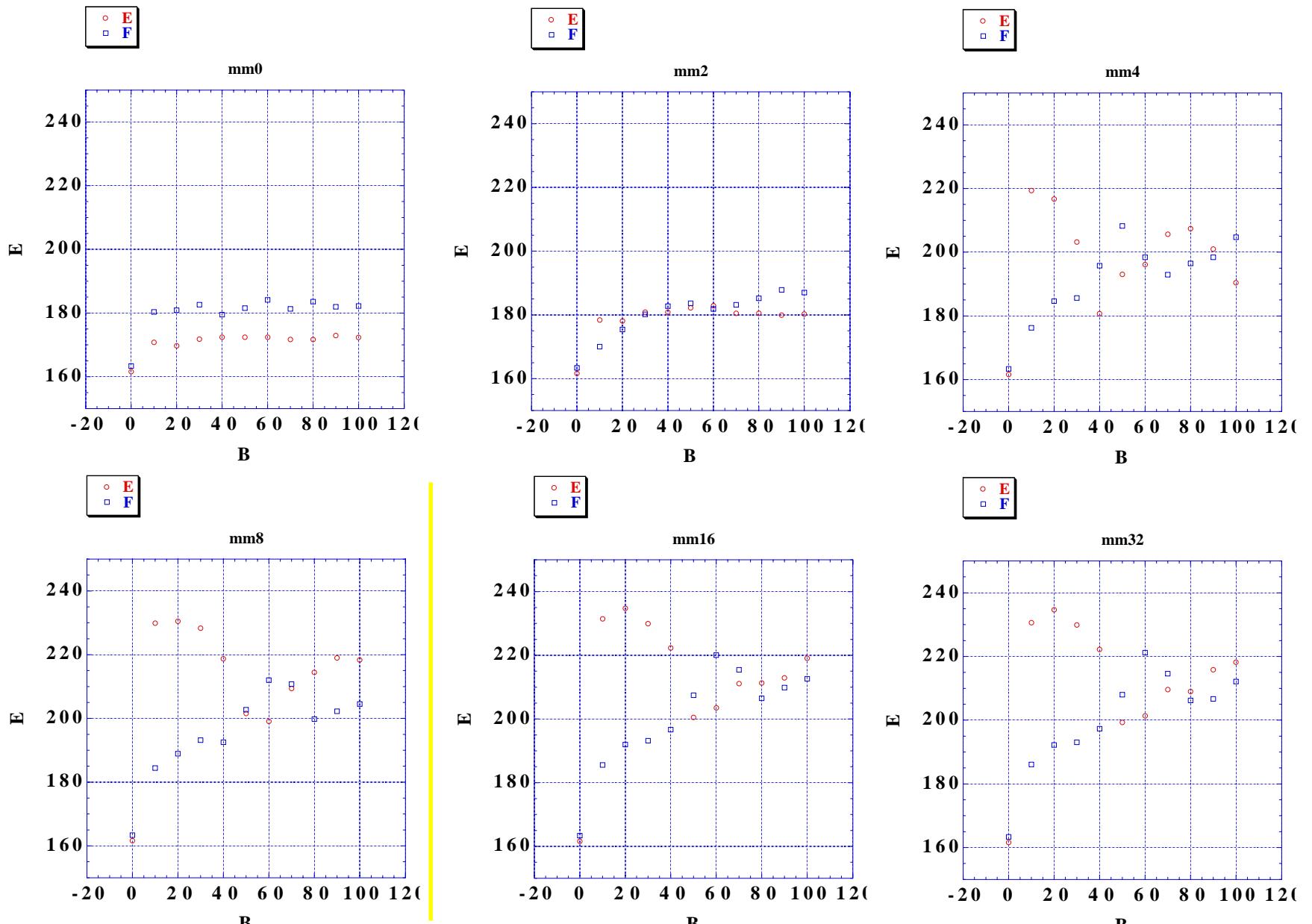
number of radial grids

nmp=10000, mmode=16, ds=1m

20A, 99%Q



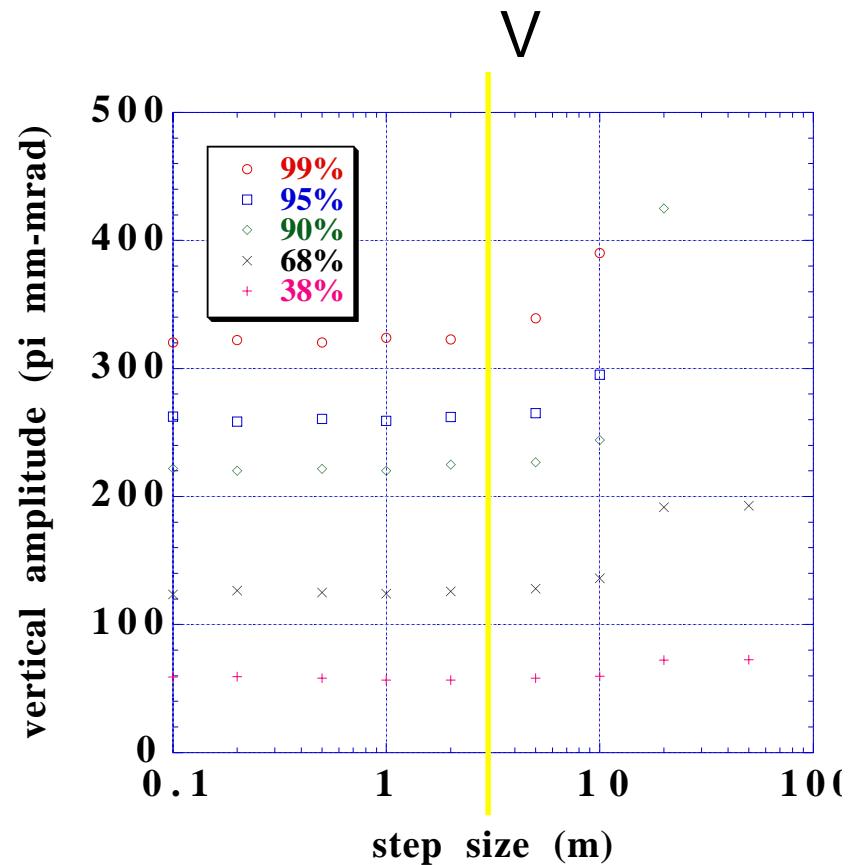
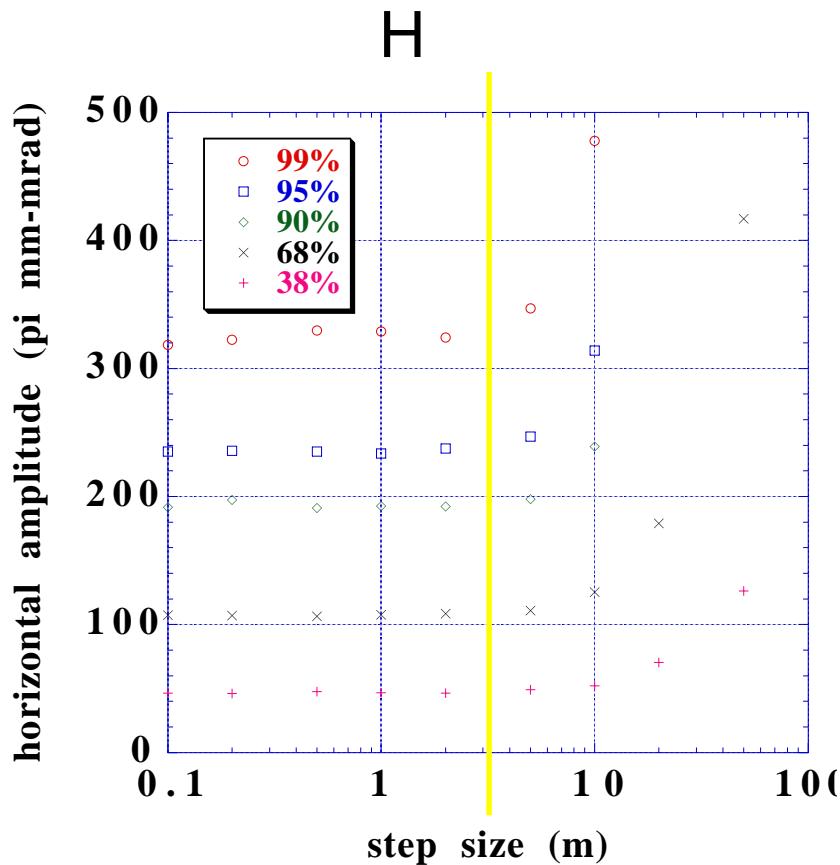
Azimuthal mode number



integration step size

nmp=10000, nrg=20, mmode=16, ds=1m

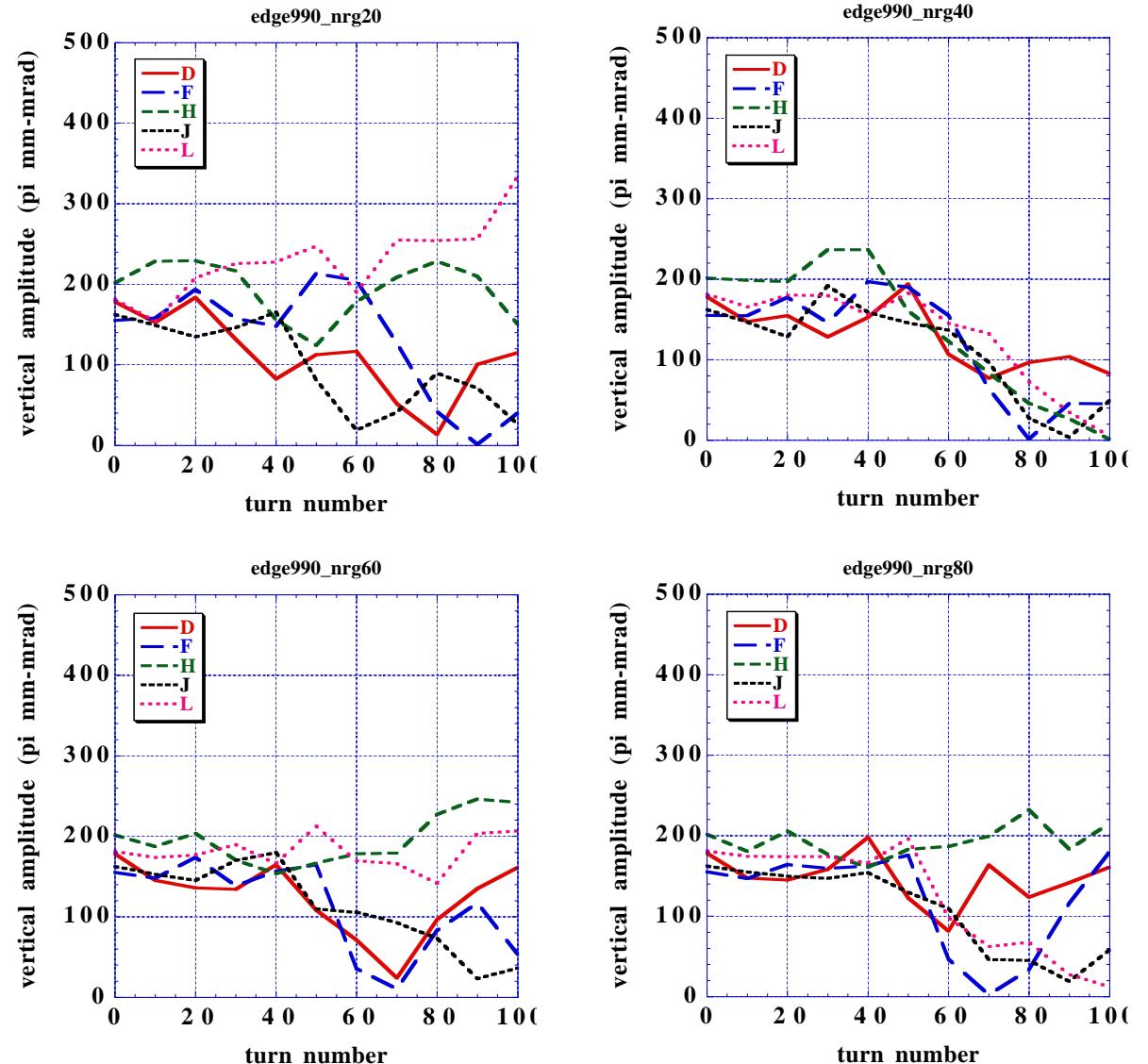
20A, 99%Q



Single particle behavior

After optimizing the parameters, still single particle motions depends on grids size, for example.

Any rational reasons?



What we already know and what we want to know

We already know

1. Coherent tune shift is a relevant measure, not incoherent.
2. Difference of coherent and incoherent tune is the largest ($5/8$) in quadrupole mode. The higher the coherent order, the smaller the difference.
3. Those picture is valid in 2D, not so clear in a 3D bunched beam.

We want to know

4. Is the coherent picture sufficient, especially for tail particles?
5. Is it still the correct picture in a 3D bunched beam?

Beam behaviour near a resonance

With and without quadrupole imperfections, see the core and tail as a function of intensity.

Four intensity levels.

- a) Neither incoherent or Q coherent does not satisfy resonance.
- b) Incoherent is below the resonance but Q coherent is above.
- c) Both incoherent and coherent is below resonance.
- d) Even larger intensity than c).

RCS is the model lattice, but assume a matched beam so that we can study MR type space charge effects based on the RCS lattice.

Tune shift with space charge effects

incoherent tune shift:

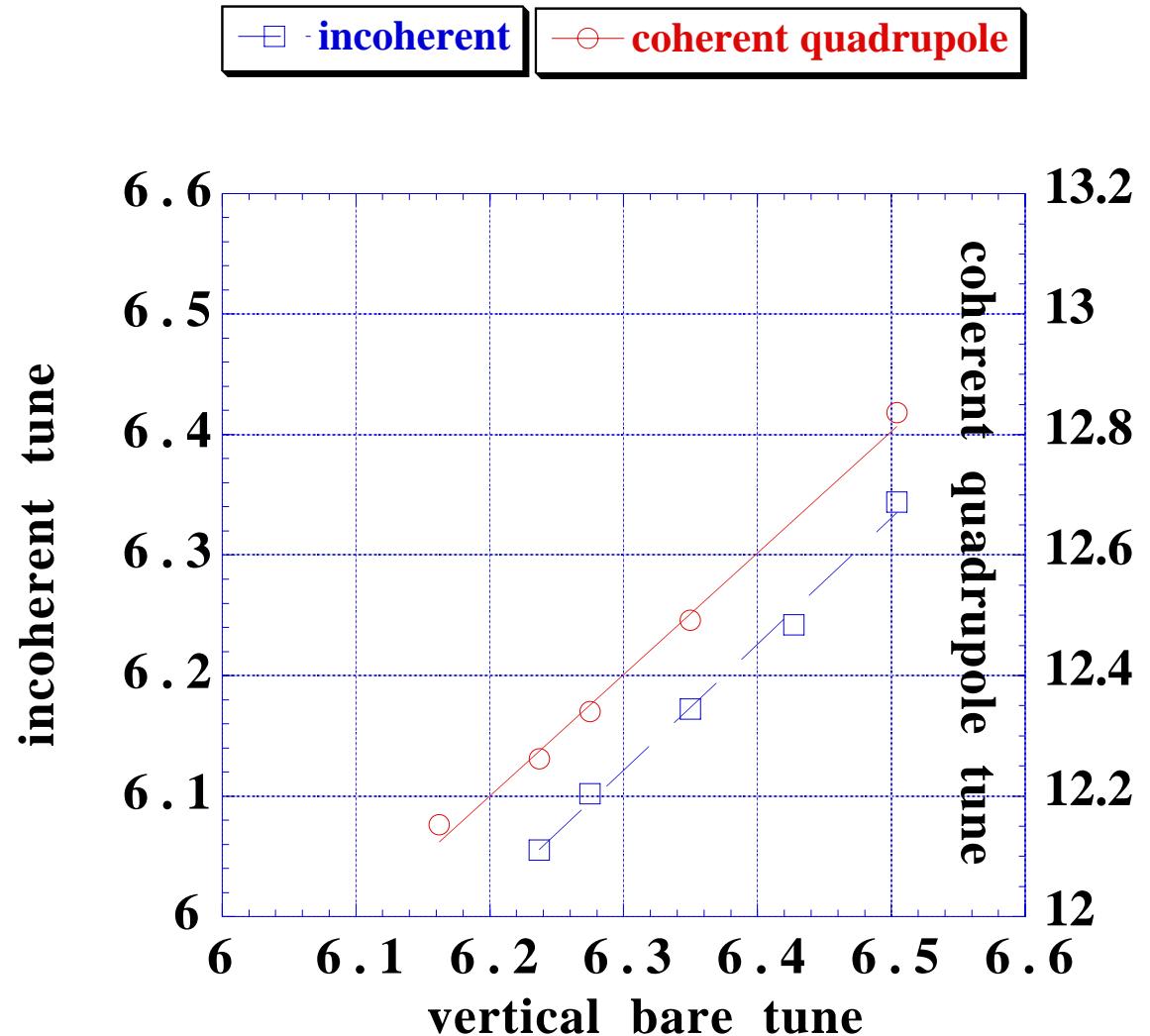
-0.16

coherent quadrupole shift:

-0.20

agrees with envelope eqs.

ic t. s. = $4/5$ cq t.s.



Two different kinds of resonance

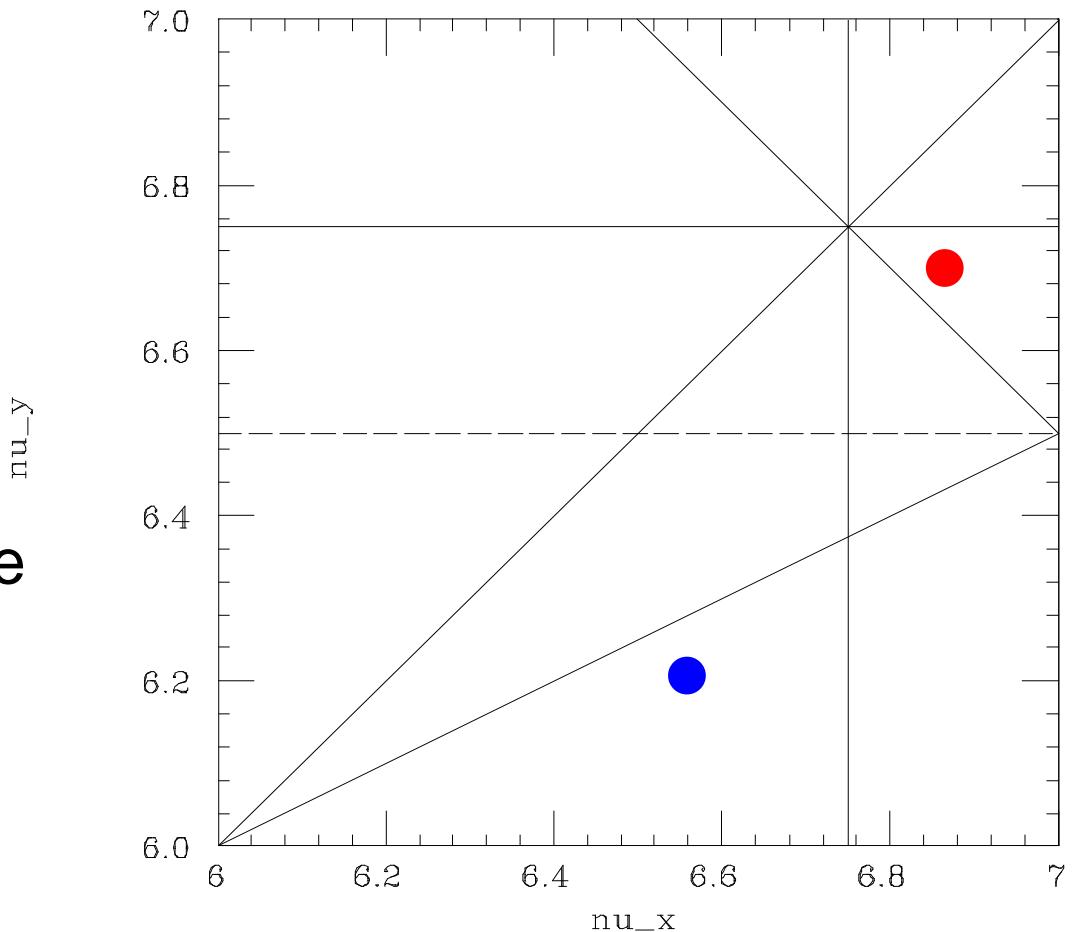
A. (6.566, 6.200)

Resonance line at $\nu_y=6.0$ is all structure ones. (S.P.=3)

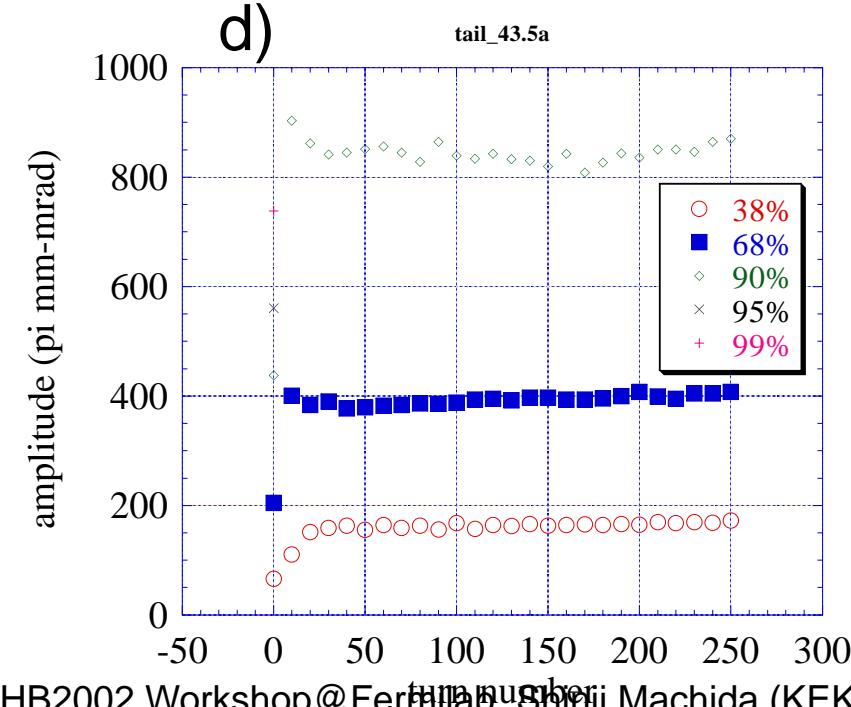
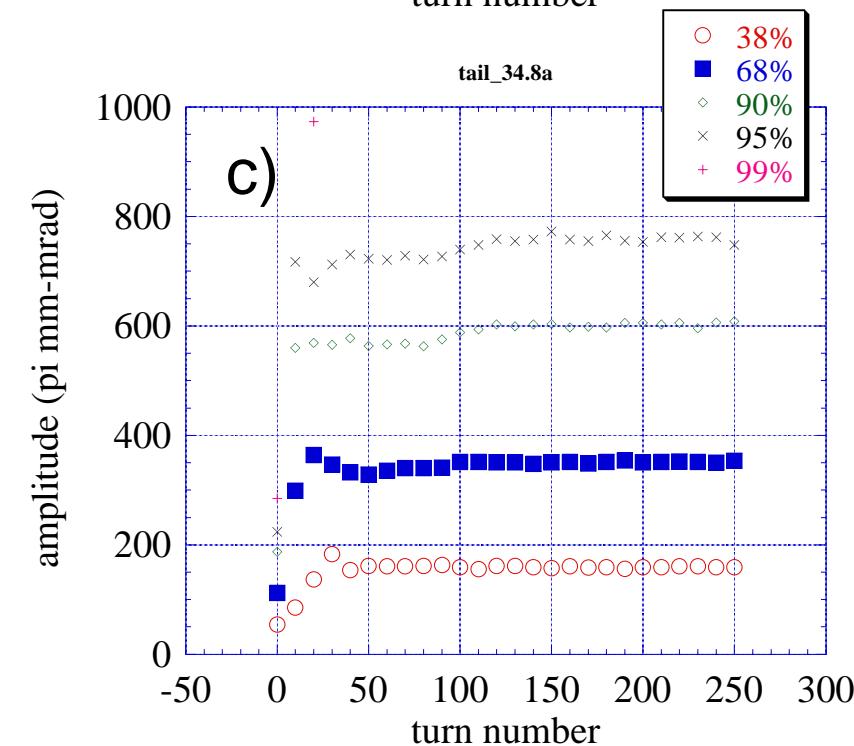
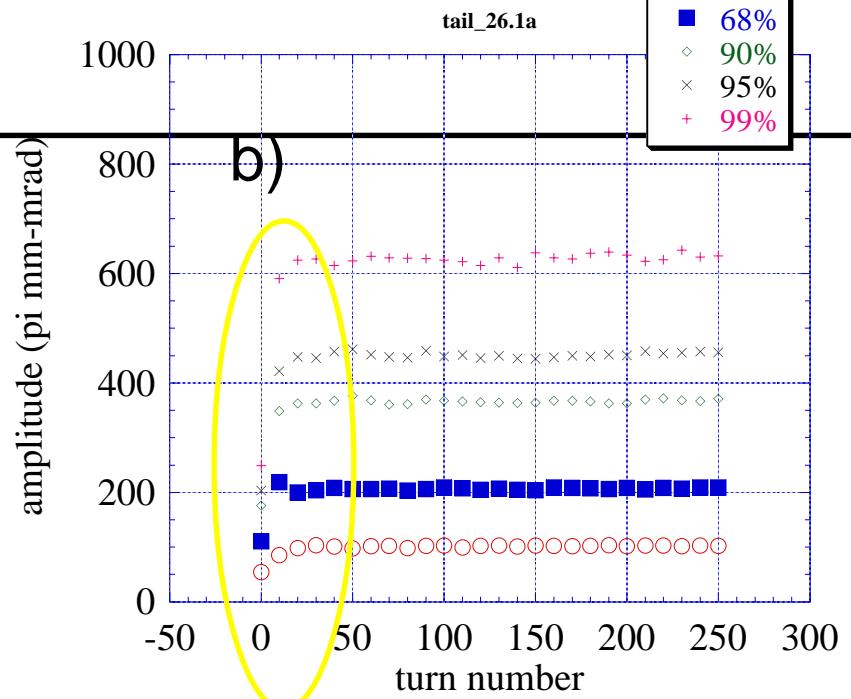
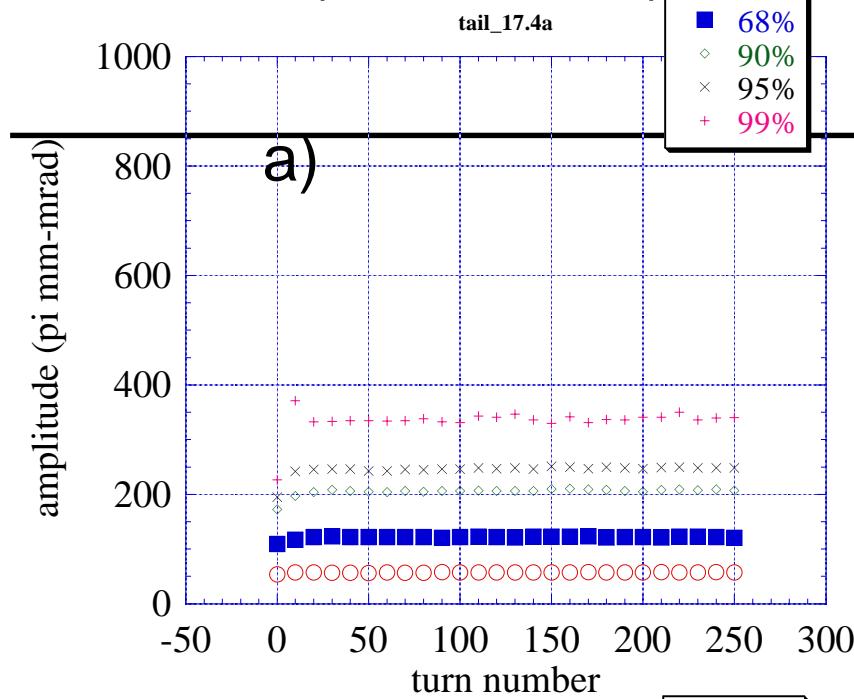
B. (6.850, 6.700)

Resonance line at $\nu_y=6.5$ is non strucure. Unless quadrupole field imperfection is included, it is transparent.

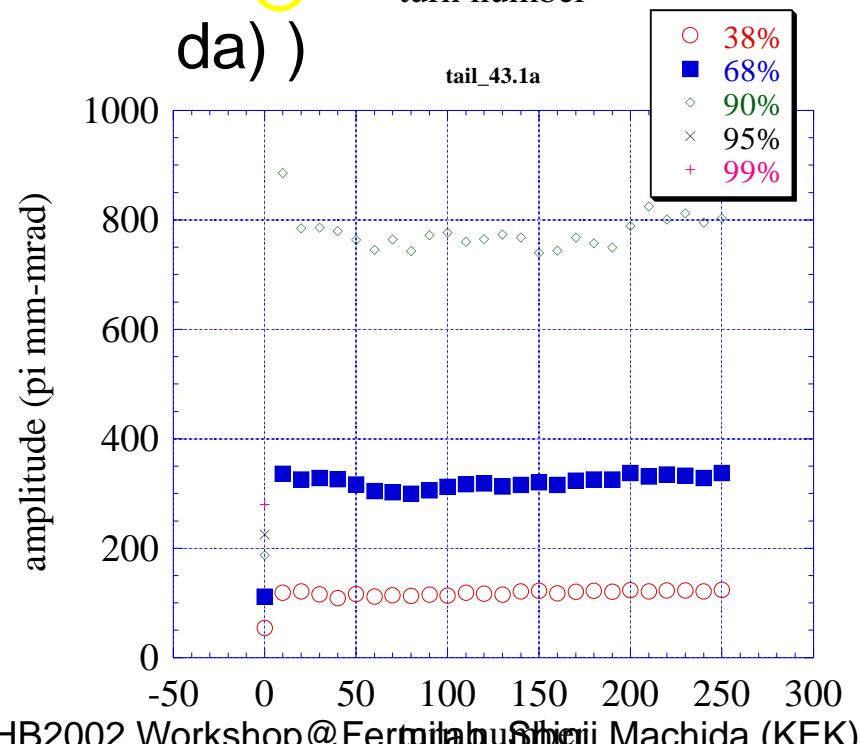
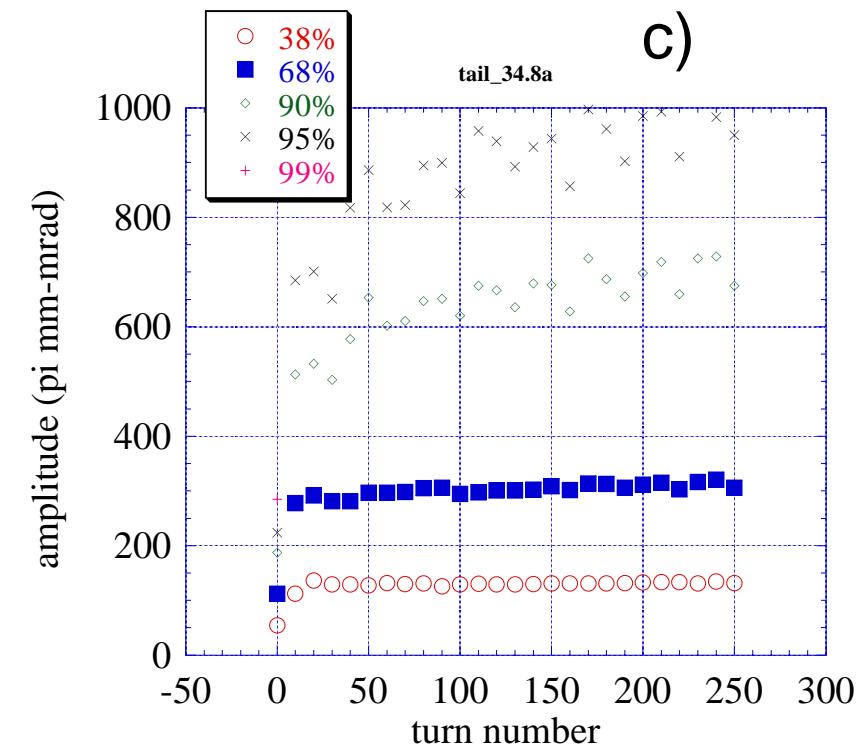
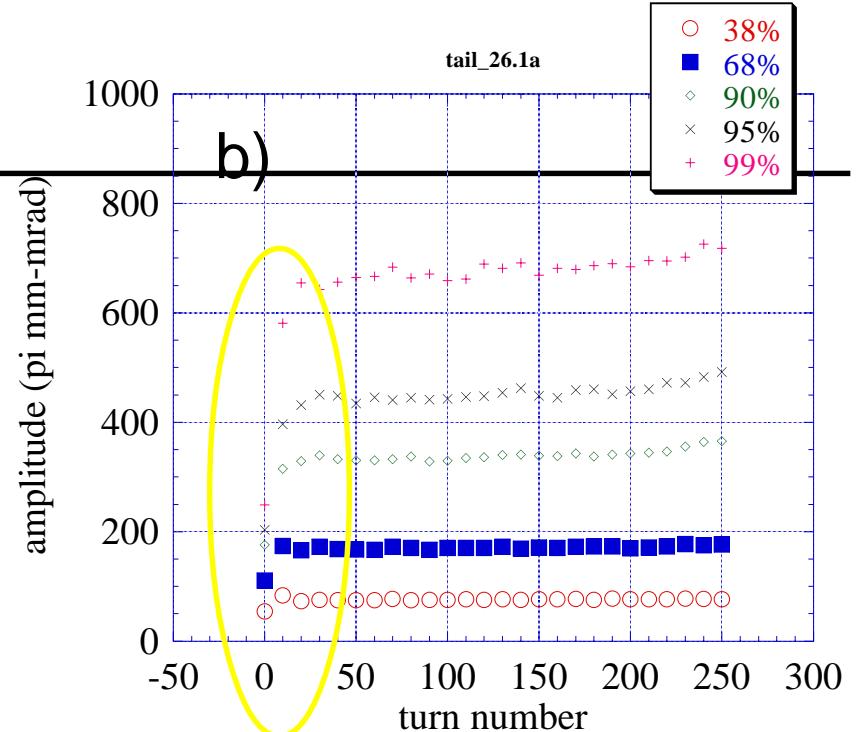
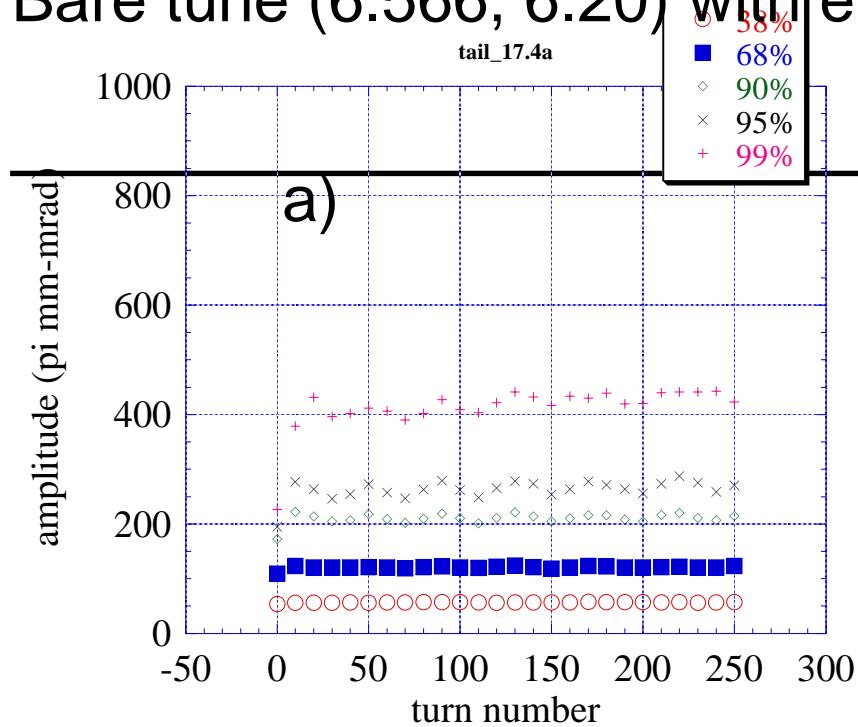
(we assume field imperfection of 0.02.)



Bare tune (6.566, 6.20) without errors



Bare tune (6.566, 6.20) with errors



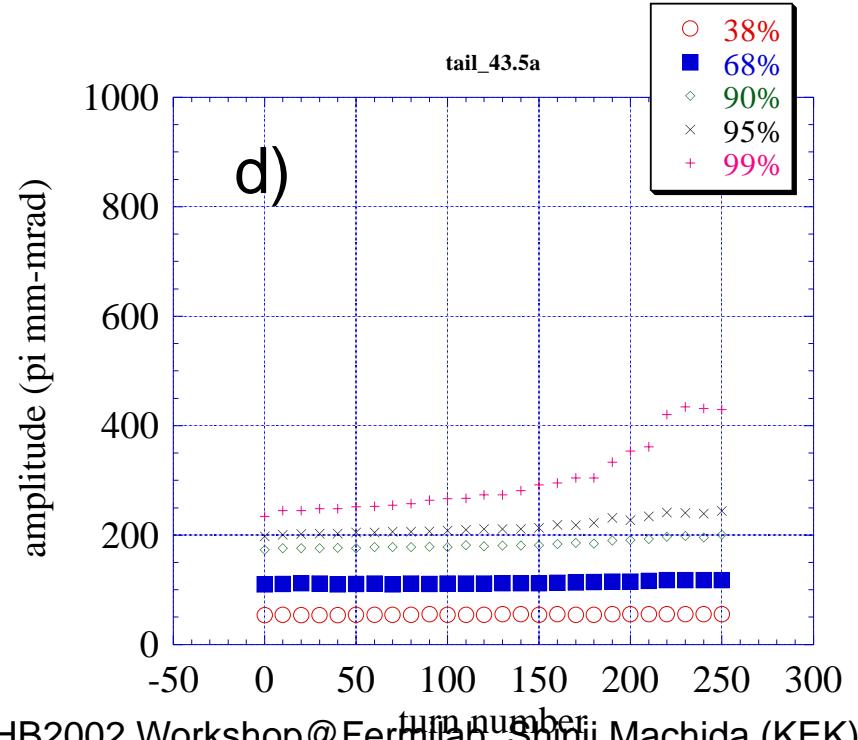
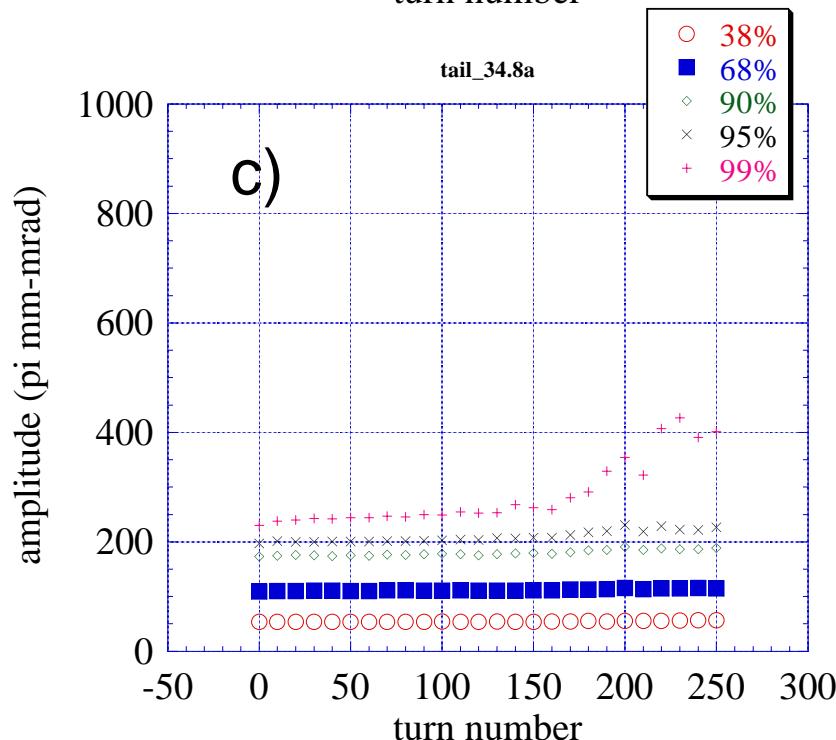
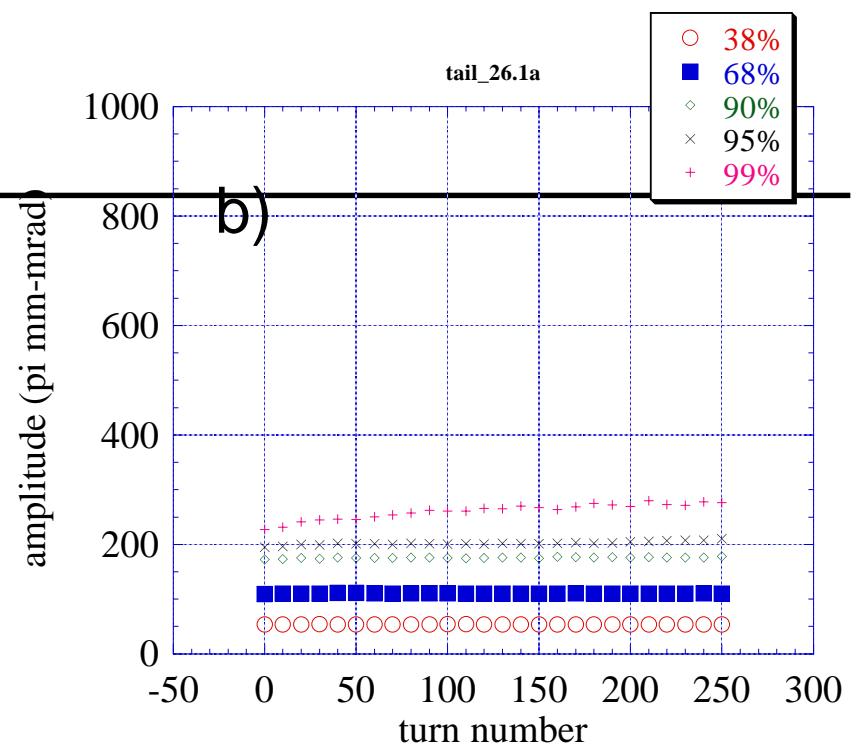
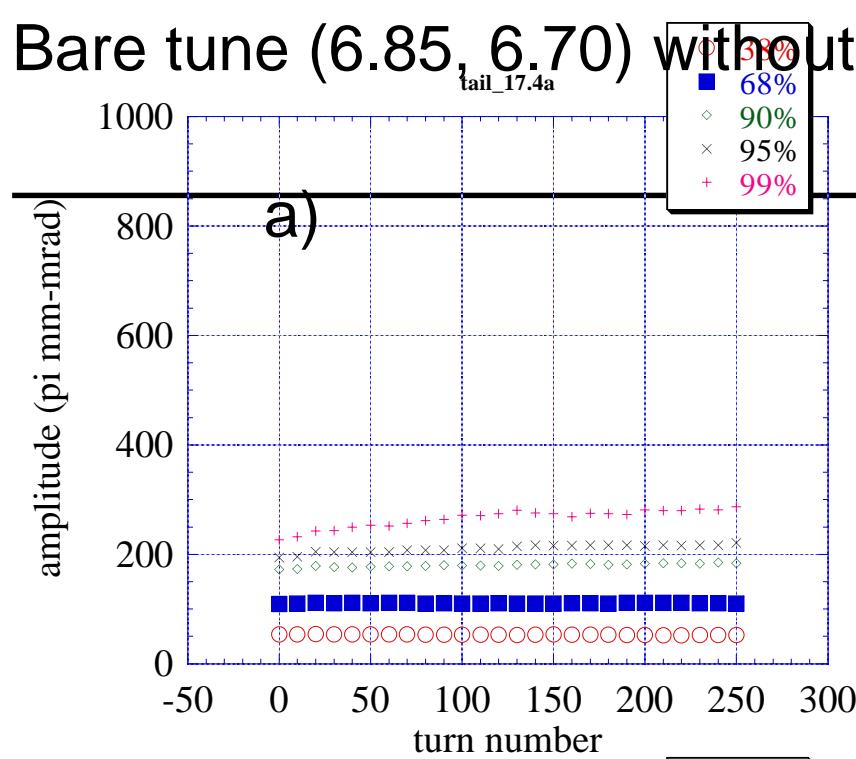
A. (6.566, 6.200) Resonance line at $\nu_y=6.0$ (structure in all order)

When the incoherent tune shift is below the resonance, core growth occurs. In fact, this is not because by incoherent tune, but by higher order coherent.

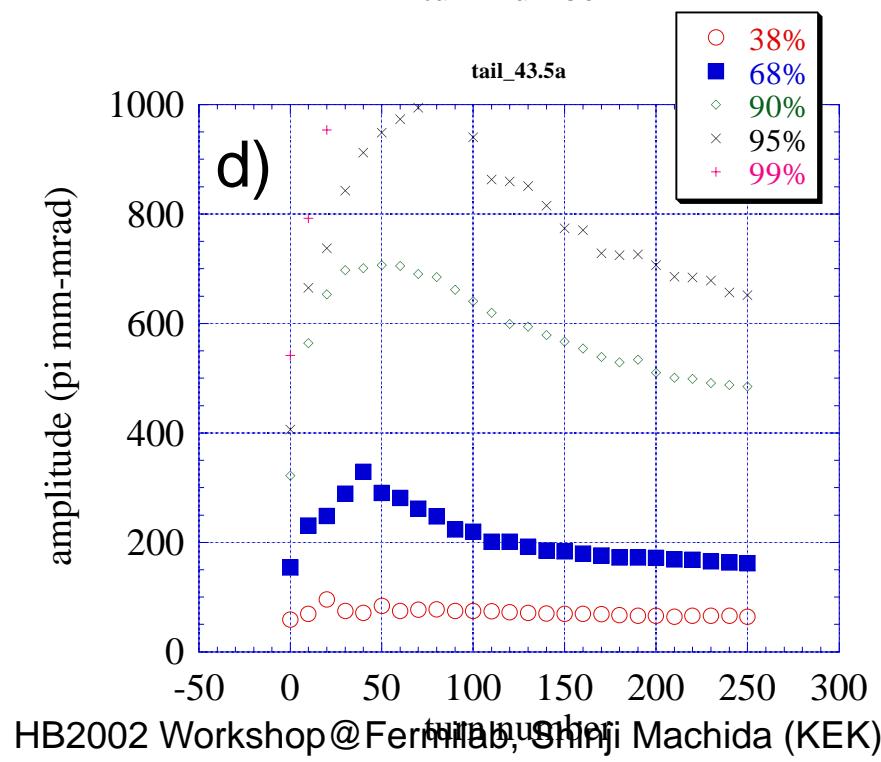
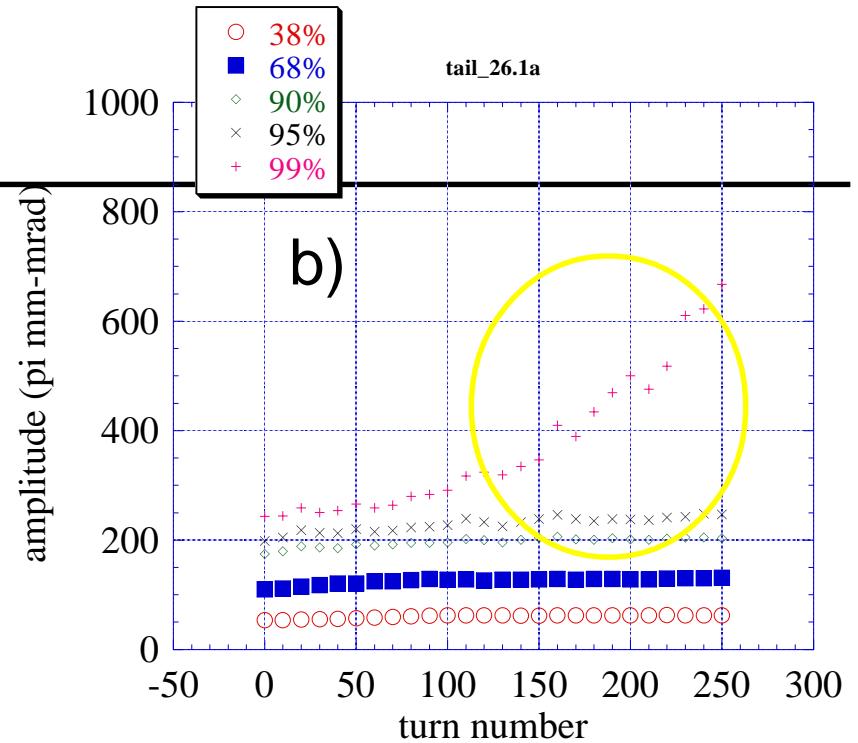
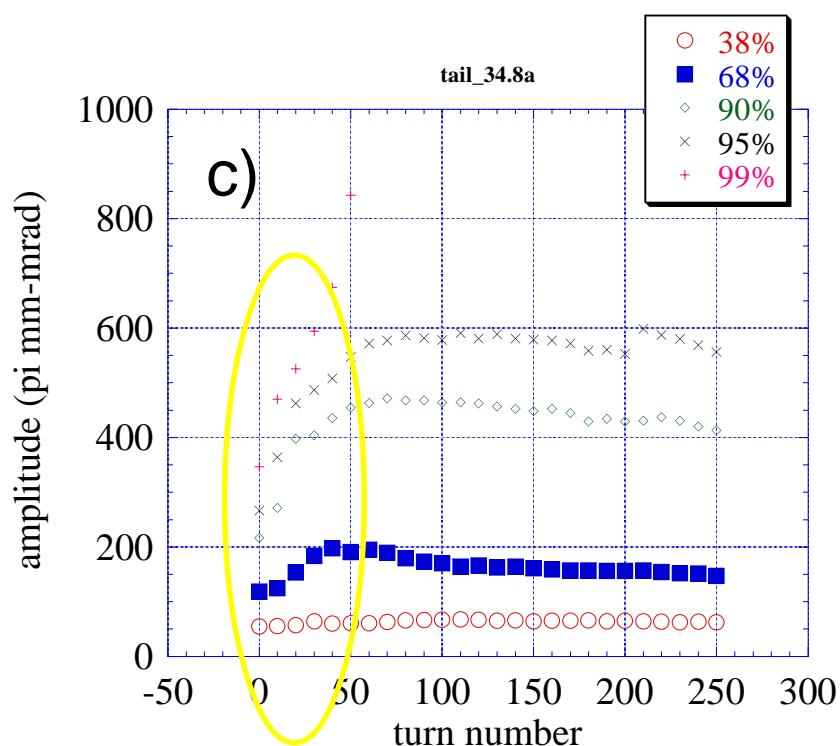
Behaviour does not change with and without quadrupole error fields (also because of higher order coherent.)

Practically, "incoherent tune shift" is a good measure.

Bare tune (6.85, 6.70) without errors



Bare tune (6.85, 6.70) with errors



B. (6.850, 6.700) Resonance line at $\nu_y=6.5$ (non strucure)

Core growth is observed only when the quadrupole coherent shift is large enough.

Tail particle (99%) start growing below the above intensity.

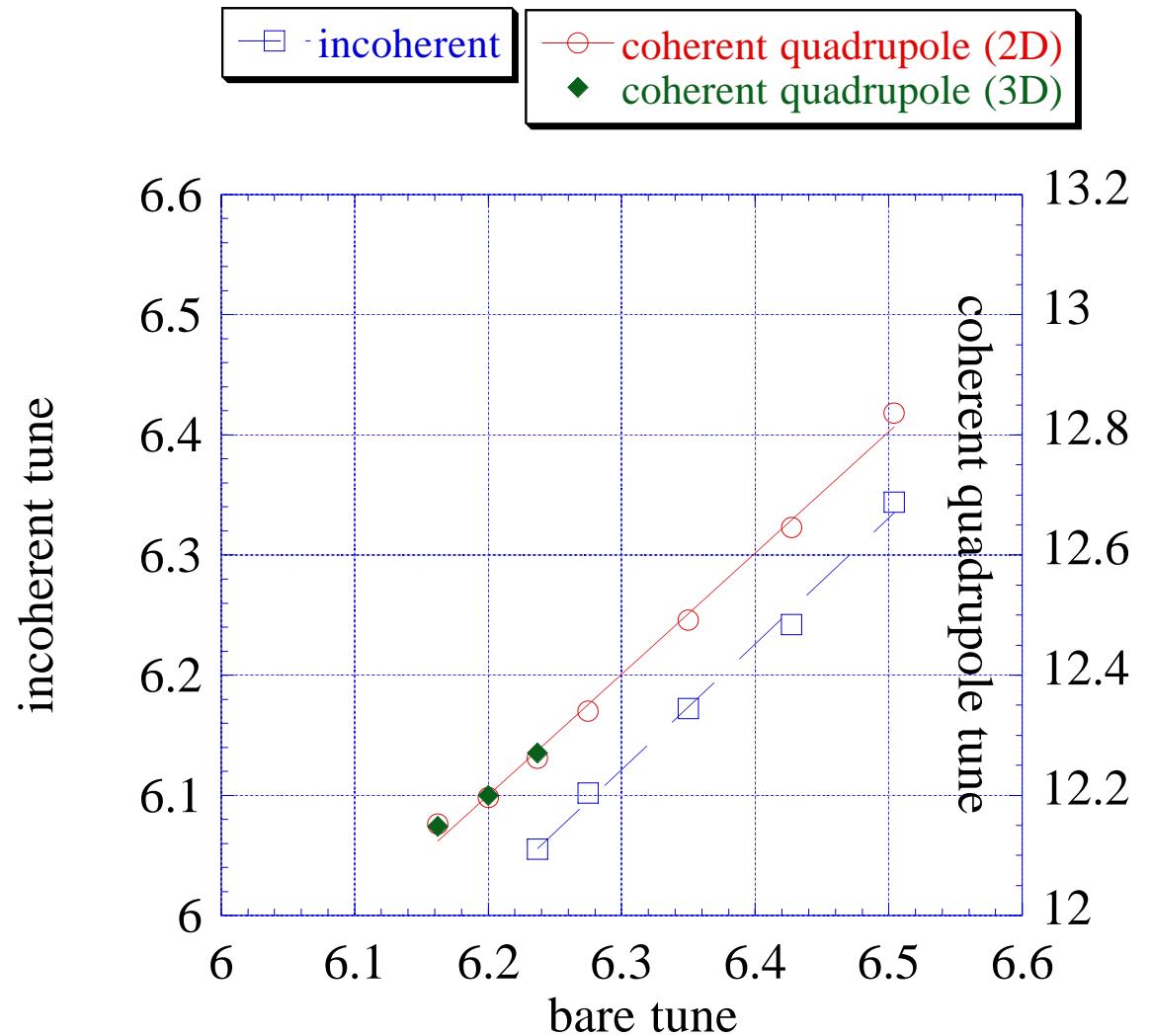
Coherent oscillations of a bunched beam

We look at coherent motions of each longitudinally sliced beam.

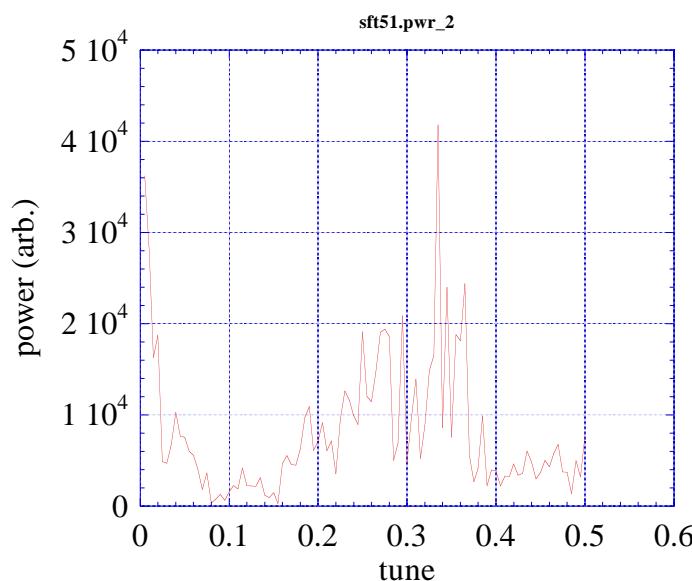
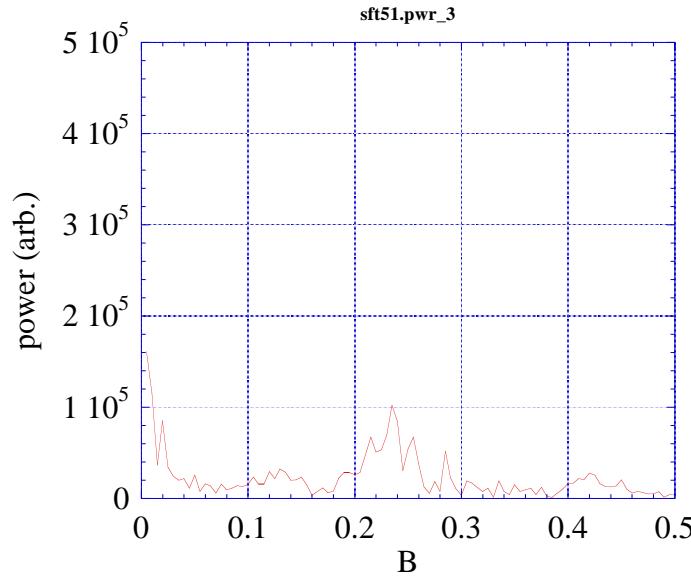
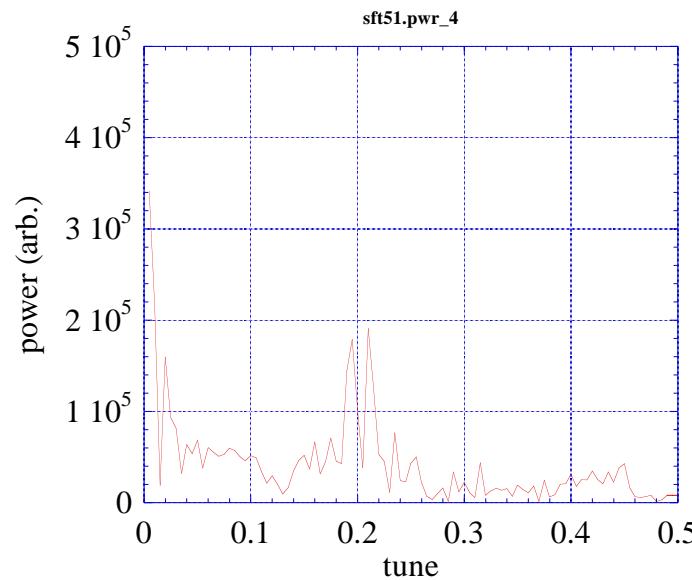
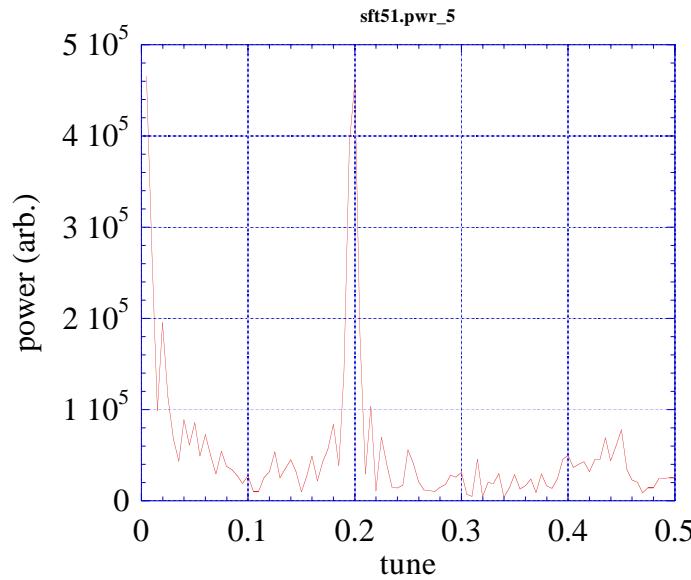
(This becomes possible thanks to faster CPUs. In 1998, the results was not clear.)

coherent tune shift of a bunched beam

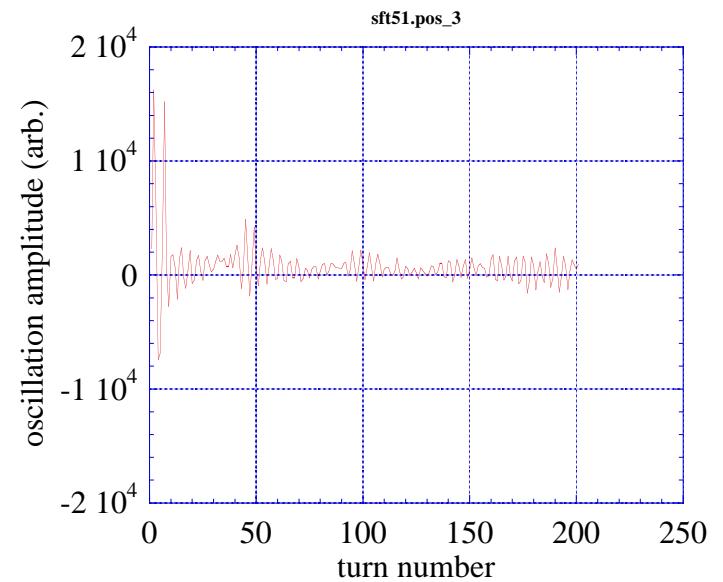
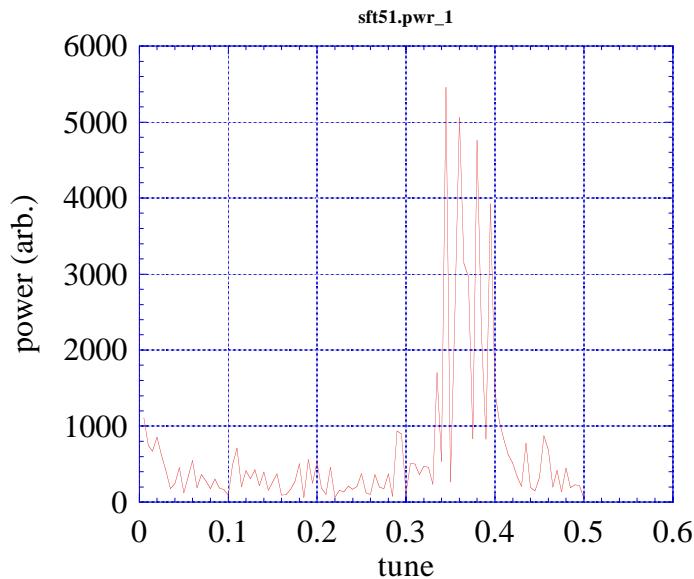
When the line density of the bunch center is the same, coherent tune shift of the center slice is the same as a 2D beam.



coherent tune spectra of each slice

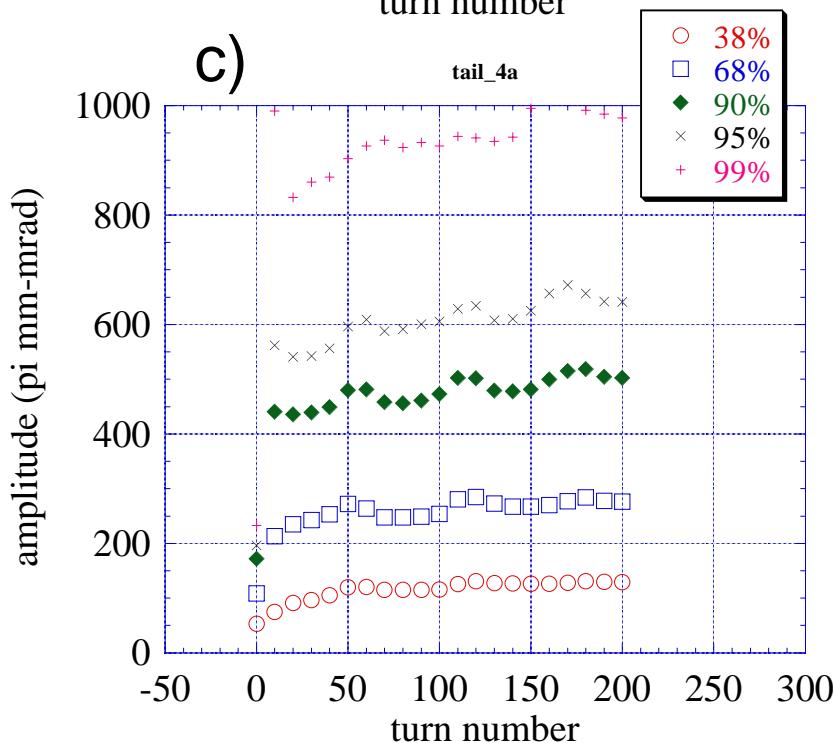
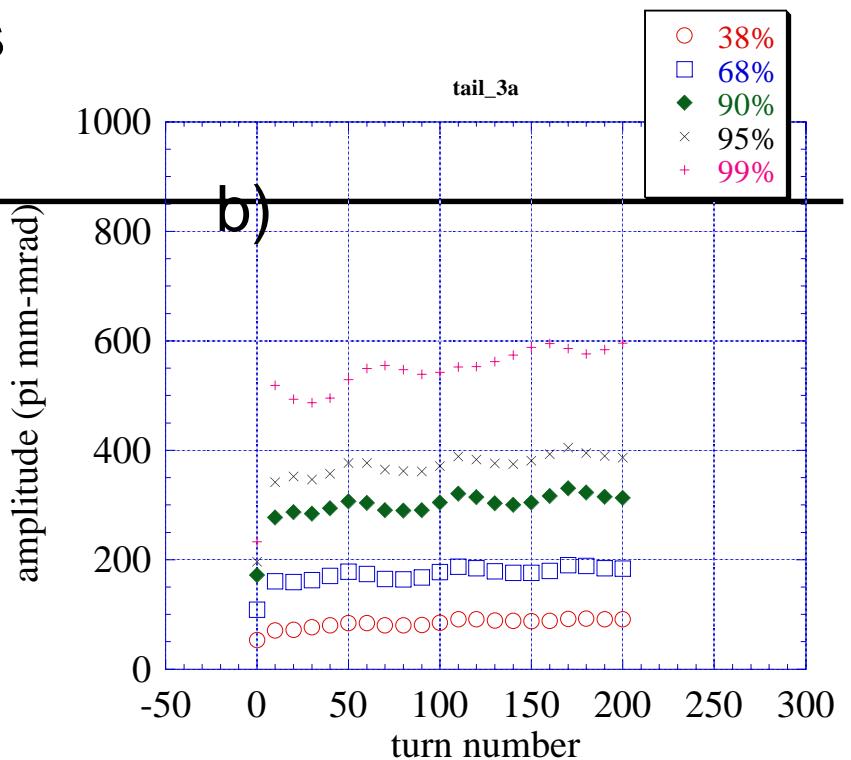
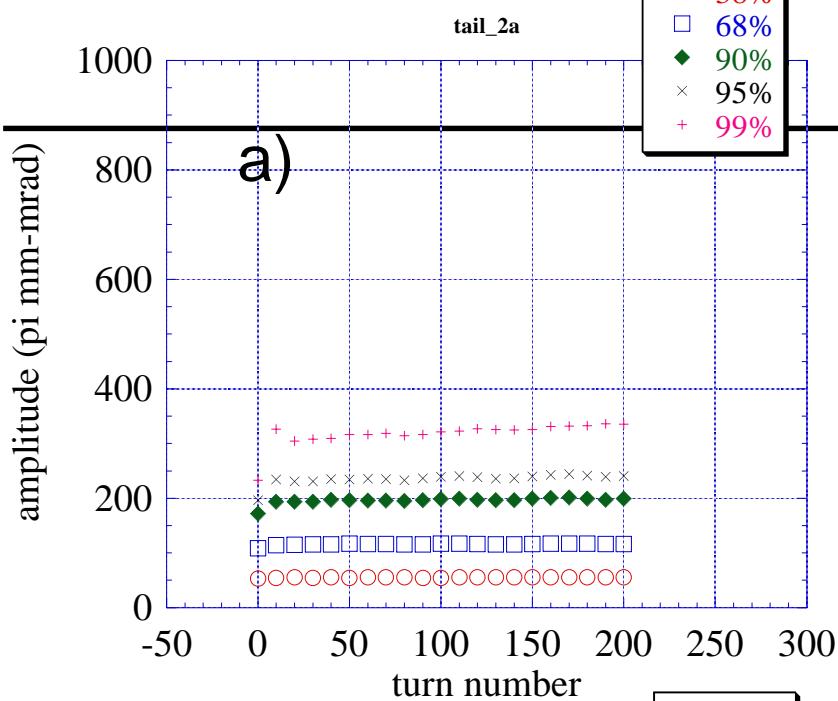


coherent tune spectra of each slice (cont.)

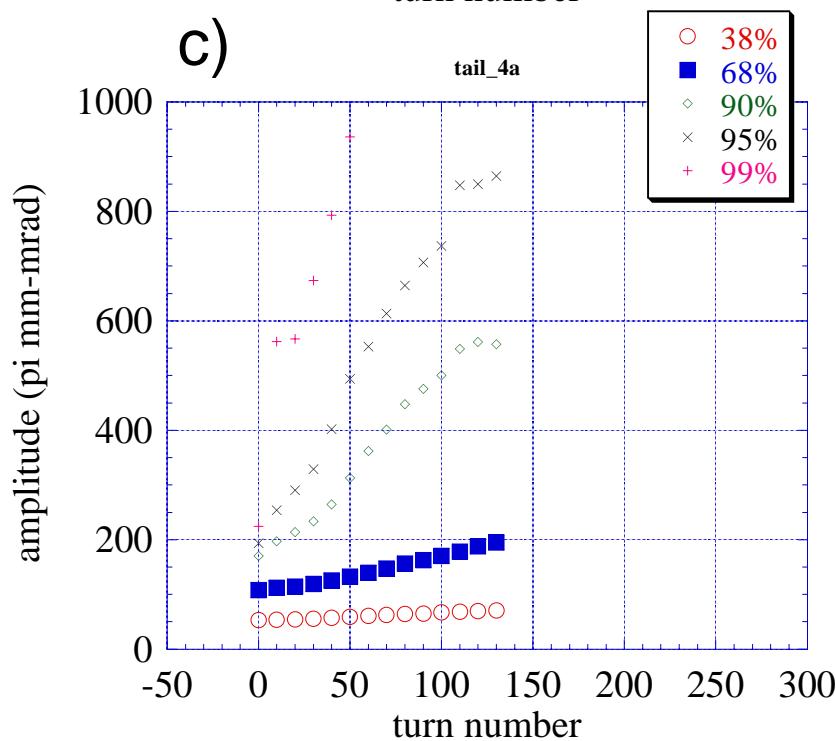
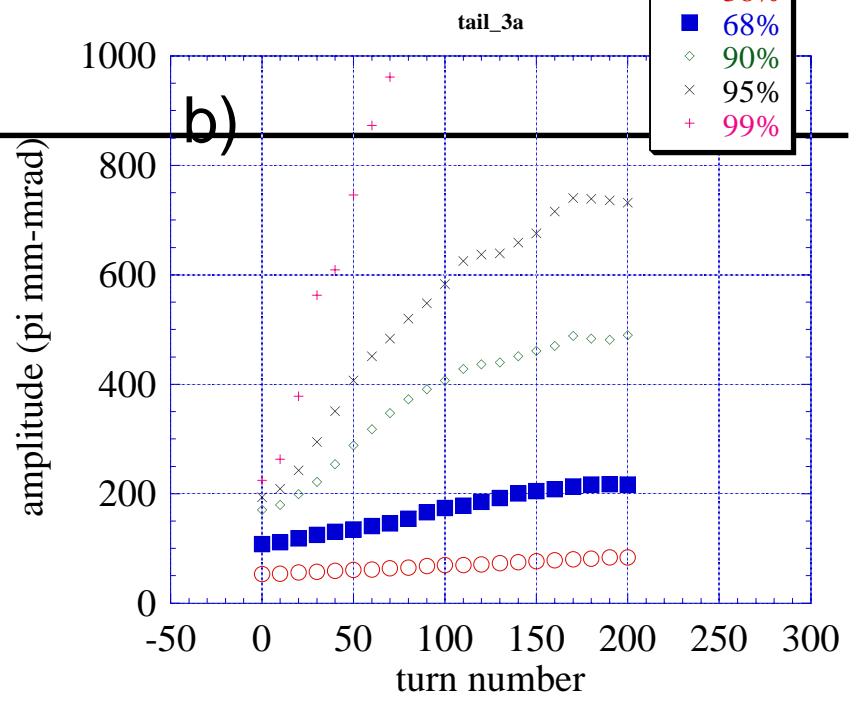
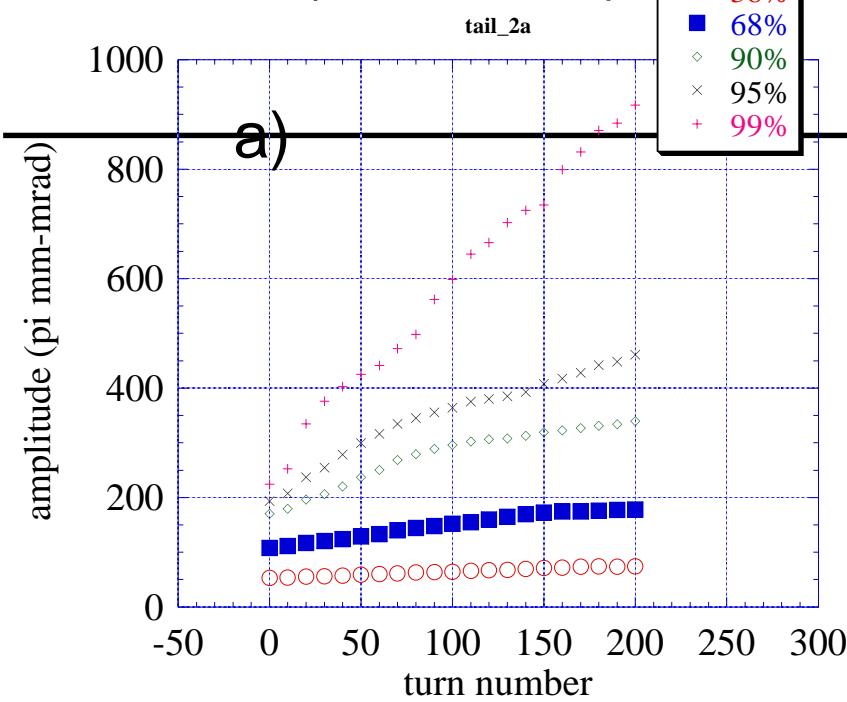


Peak separation is not directly the same as synchrotron tune.

Bare tune (6.566, 6.20) without errors



Bare tune (6.85, 6.70) with errors



Summary of a bunched beam

At $v_y=6.0$, the behavior is similar to 2D. When the incoherent tune shift is large enough, there is a core and tail growth.

At $v_y=6.5$, the incoherent threshold becomes not clear.

Summary

1. Saturation of parameters of pace charge code is checked.
2. There are a couple of questions, namely
 - Is the coherent picture sufficient, especially for tail particles?
 - Is it still the same in a 3D bunched beam?
3. There are no clear answer yet. However, tail or halo growth may not be completely described by coherent picture.
4. Near the integer resonance, higher order coherent modes, not just quadrupole, should be considered. As a results incoherent tune shift may be a good measure. (Is this against CERN PS and PSR data?)
5. In a bunched beam, a clear threshold due to coherent tune shift seems disappear..